

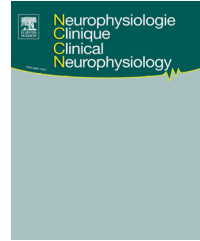


Disponible en ligne sur

**ScienceDirect**  
[www.sciencedirect.com](http://www.sciencedirect.com)

Elsevier Masson France

**EM|consulte**  
[www.em-consulte.com/en](http://www.em-consulte.com/en)



ORIGINAL ARTICLE/ARTICLE ORIGINAL

# The feasibility of home polysomnographic recordings prescribed for sleep-related neurological disorders: A prospective observational study



*La faisabilité des enregistrements polysomnographiques à domicile prescrits dans les troubles neurologiques du sommeil : une étude observationnelle prospective*

N. Carpentier<sup>a,\*</sup>, J. Jonas<sup>a,b,c</sup>, J.-L. Schaff<sup>a</sup>,  
L. Koessler<sup>c</sup>, L. Maillard<sup>a,b,c</sup>, H. Vespignani<sup>a,b,c</sup>

<sup>a</sup> Neurology Department, University Hospital of Nancy, 29, avenue du Maréchal-de-Lattre-de-Tassigny, 54000 Nancy, France

<sup>b</sup> Faculty of Medicine, University of Lorraine, 54500 Vandœuvre-lès-Nancy, France

<sup>c</sup> UMR 7039, Center for Automatic Control of Nancy (CRAN), CNRS University of Lorraine, 54500 Vandœuvre-lès-Nancy, France

Received 18 October 2013; accepted 7 August 2014

Available online 23 August 2014

## KEYWORDS

Polysomnography;  
Home;  
Ambulatory;  
Sleep disorders;  
Neurological  
disorders

## Summary

**Objective.** — Home polysomnography is being increasingly developed for sleep studies, with various grades of quality. This study aimed to determine the feasibility of affordable, high quality home polysomnographic recordings prescribed for suspected sleep-related neurological disorders.

**Patients and methods.** — We prospectively screened all patients referred to the specialist sleep disorders clinic in Nancy University Hospital between May 2011 and August 2011. Patients were eligible for inclusion if they required polysomnography for the diagnosis of a sleep-related neurological disorder. One-night, polysomnography was performed in each patient's home by a trained sleep technician. Financial cost was determined prior to inclusion. A recording was considered as satisfactory if all the following criteria were present: at least, one EEG channel with continuous signal allowing determination of sleep stages and wake during more than 66% of sleep time; at least, one usable respiratory channel (airflow or either band) during more than 66% of sleep time; and usable oximetry during more than 66% of sleep time.

\* Corresponding author. Tel.: +33 3 83 85 16 86; fax number: +33 3 83 85 14 79.

E-mail address: [nic.carpentier@gmail.com](mailto:nic.carpentier@gmail.com) (N. Carpentier).

**MOTS CLÉS**

Polysomnographie ;  
À domicile ;  
Ambulatoire ;  
Troubles du sommeil ;  
Sommeil  
neurologique

**Results.** — Forty-eight of the 139 screened patients were included. Among the 48 home polysomnography recordings, 35 (72.9%) were satisfactory. Thirteen (27.1%) tracings displayed an unsatisfactory loss of EEG data, including seven (14.6%) tracings with an unsatisfactory loss of respiratory data.

**Conclusion.** — Home polysomnography prescribed for suspected sleep-related neurological disorders is feasible, with affordable costs, whilst maintaining high quality recording. Further studies are needed to measure the real medico-economic impact of promoting outpatient domiciliary explorations for sleep-related neurological disorders.

© 2014 Elsevier Masson SAS. All rights reserved.

**Résumé**

**But de l'étude.** — La polysomnographie à domicile se développe actuellement avec des niveaux de qualité variables selon le type de troubles du sommeil étudiés. Cette étude a pour objectif de montrer la faisabilité des enregistrements polysomnographiques à domicile, alliant faible coût et haute qualité, et qui sont nécessaires au diagnostic de troubles neurologiques du sommeil.

**Patients et méthodes.** — Entre mai 2011 et août 2011, les patients se présentant à la consultation spécialisée du sommeil du Centre hospitalier et universitaire de Nancy ont été évalués. Étaient éligibles les patients nécessitant une polysomnographie pour le diagnostic de troubles neurologiques du sommeil. L'enregistrement polysomnographique nocturne était réalisé à domicile par un technicien spécialisé. Le coût total de l'acte était déterminé avant les inclusions. Un enregistrement était considéré comme satisfaisant si tous les critères suivants étaient réunis : au moins une voie EEG permettant de définir le stade de sommeil sur minimum 66 % du temps total de sommeil, au moins une voie respiratoire (débit ventilatoire ou sangles) sur minimum 66 % du temps total de sommeil, et l'oxymétrie analysable sur minimum 66 % du temps total de sommeil.

**Résultats.** — Quarante-huit des 139 patients évalués ont été inclus. Sur les 48 enregistrements, 35 (72,9 %) étaient satisfaisants. Treize (27,1 %) enregistrements ont présenté une perte non satisfaisante des signaux EEG, incluant les sept (14,6 %) enregistrements avec une perte non satisfaisante des signaux respiratoires.

**Conclusion.** — La polysomnographie à domicile prescrite chez les patients suspects de troubles neurologiques du sommeil est donc réalisable. Les coûts sont faibles mais la qualité reste suffisamment haute. Des études complémentaires sont nécessaires pour mesurer l'impact médico-économique réel des explorations du sommeil neurologique à domicile.

© 2014 Elsevier Masson SAS. Tous droits réservés.

**Introduction**

Polysomnography (PSG) is an indispensable method for sleep studies. Two types of PSG are currently defined: attended sleep-laboratory PSG and the unattended home PSG [8]. Home PSG (HPSG) is becoming an alternative to sleep-laboratory PSG for the diagnosis of some sleep disorders. It has been used for the assessment of sleep architecture in children with attention deficit hyperactivity disorder [9]. HPSG has been also fully validated for the assessment of suspected obstructive sleep apnea (OSA) in adults [6]. Indeed in OSA, the quality of sleep (sleep efficiency) has shown in a Belgian study to be better with HPSG compared to sleep-laboratory PSG [5].

The main drawback of HPSG compared to sleep-laboratory PSG is the possibility of sensor loss, which can be detected but not self-resolved. To take this drawback into account, international grades of quality of HPSG have been defined for the Sleep Heart Health Study (SHHS) cohort [14]. This cohort prospectively focused on the relationships between sleep disturbances and cardiovascular morbidity,

but not specifically on sleep-related neurological disorders. The grade "good" required at least 5 hours (or 50% of sleep time) of continuous signal for at least one EEG channel, one respiratory channel and oximetry.

The feasibility of HPSG recordings prescribed for sleep-related neurological disorders may be different than for sleep-related breathing disorders, because patients are more likely to move during sleep with a higher probability of sensor loss (e.g. parasomnia or sleep-related movement disorders). Moreover, the needed time of recording is longer, for example, to estimate sleep efficiency in insomnia, or to record late rapid eye movement (REM) phases for REM sleep behavior disorders. However, the feasibility of HPSG recordings prescribed for sleep-related neurological disorders has never been specifically studied.

The aim of this study was to determine the feasibility of affordable HPSG recordings prescribed for sleep-related neurological disorders. We chose to increase the required proportion of continuous signal for the three main channels from 50% (i.e. grade "good") to 66% of sleep time, in order to consider a PSG recording as satisfactory.

## Methods

### Patients

We prospectively screened all patients referred by specialists and general practitioners to the specialist sleep disorders clinic of the department of Neurology in Nancy University Hospital between May 2011 and August 2011. All patients were examined by a clinician specialized in sleep medicine. Patients were eligible for inclusion if they lived in the federation of municipalities of Nancy and if they required PSG for the diagnosis of one of the following suspected sleep-related neurological disorders: narcolepsy with or without cataplexy, periodic limb movement disorder, parasomnias, severe insomnia symptoms, neurological disease with sleep disturbance, and suspected comorbid sleep-related breathing disorder. All patients gave their written informed consent to participate and the French Regional Health Agency (RHA) approved the study.

### Procedure

A one-night HPSG was performed in each patient's home by a trained sleep technician, employed by the home medical care society HADAN<sup>®</sup> of Nancy. The sleep technician had previously participated in a self-training video-assisted program for performing HPSG and the quality of learning, then evaluated in the sleep laboratory by a clinician specialized in sleep medicine (J.-L. S.), before the onset of the study. The sleep technician brought the necessary equipment to the patient's home. He explained the HPSG procedure to the patient and provided a contact telephone number for emergency or supplementary information if needed. He installed the material and checked the quality of the signal, ensuring optimal acquisition of data before leaving the patient's home. The sleep technician returned the following morning to remove the equipment. He then transmitted the data to the Nancy sleep laboratory for interpretation. All PSG data were reviewed for signal quality and scored by a specialized clinician in sleep medicine, experienced in PSG interpretation (H.V. or J.-L. S.). Sleep was scored according to the American Academy of Sleep Medicine rules [10]. For patients suspected for narcolepsy, a Multiple Sleep Latency Test (MSLT) was performed in-laboratory, the day following the HPSG.

### HPSG device

The device was Morpheus (Micromed<sup>®</sup>). This portable device allowed recording of six electroencephalogram (EEG) channels (C3, C4, O1, O2, T3, T4, Fz as reference, Pz as ground, system 10/20, sampling rate 256 Hz, filter 50 Hz, electrical impedance < 5KOhm), left and right electrooculogram channels, two submental electromyogram (EMG) bipolar leads, two left and two right anterior tibialis EMG bipolar leads, two electrocardiogram bipolar leads, oro-nasal airflow (thermistor), transcutaneous oxyhemoglobin saturation (pulse oximetry), expired CO<sub>2</sub> (nasal capnograph), thoracic

and abdominal movements (piezoelectric sensors attached to circumferential body bands). Sensors were fixed on the skin using water-soluble conductive adhesives (EC2, Grass Technologies<sup>®</sup>). Data were stored on a flash removable storage disk. PSG data were analyzable with REMbrandt<sup>®</sup> software (Micromed<sup>®</sup>). Due to confidentiality issues, the RHA rejected the use of video recording in the context of this pilot study.

### Costs

The HPSG costs were determined prior to patient inclusions, in agreement with the RHA. The cost of a one-night HPSG was 350€ and detailed as follows: 90€ for the intervention at home of the sleep technician employed by HADAN<sup>®</sup>, 70€ for the interpretation of the HPSG recording by the specialist in sleep medicine, 140€ for the delivery and the use of HPSG portable device (Morpheus, Micromed<sup>®</sup>), and 50€ for data management by Clinact<sup>®</sup> society, including the electronic transmission of the final medical report to the general practitioner.

### Outcomes

A recording was considered as satisfactory if all the following criteria were present: at least one EEG channel with continuous signal to distinguish sleep from wake and to determine sleep stages during more than 66% of sleep time; at least one respiratory channel (airflow or either band) usable during more than 66% of sleep time; and oximetry usable during more than 66% of sleep time. The diagnosis of sleep disorders was based on the second edition of the International Classification of Sleep Disorders [1]. In the absence of video recording, parasomnias were only investigated to exclude nocturnal frontal lobe seizures.

## Results

Among 139 patients prospectively screened, 48 fulfilled the criteria of inclusion (sex-ratio = 1:1; age min-max = 24–82 years). No patient refused enrolment. Forty-eight HPSG were performed and among these, 35 (72.9%) were satisfactory. Two HPSG tracings (4.2%) were non-interpretable due to the complete loss of EEG signal during the night. Eleven additional HPSG tracings (22.9%) displayed EEG data available for less than 66% of sleep time, of which six (12.5%) for less than 33% of sleep time. No tracing showed complete loss of respiratory channels during the night. Seven tracings (14.6%) displayed respiratory data available for less than 66% of sleep time, of which one (2.1%) for less than 33% of sleep time. All patients had oximetry available during the entire night. The seven unsatisfactory tracings based on respiratory criteria were also unsatisfactory tracings based on EEG criteria, so that only 13 HPSG recordings (27.1%) were finally unsatisfactory.

Seventeen patients (35.6%) were suspected of well-defined sleep-related neurological disorders, whereas almost one half of them (41.7%) exhibited severe insomnia symptoms (Table 1). Comorbid sleep-related breathing disorders were suspected in 11 patients (22.9%). The home polysomnography contributed to the positive diagnosis of

**Table 1** Suspected sleep disorders (or main complaints) before home polysomnography and conclusions of home polysomnography.

Suspected sleep disorders/Main complaints before HPSG	Number of patients (%)
Narcolepsy	2 (4.2)
Periodic limb movement disorder	5 (10.5)
Parasomnia	2 (4.2)
Severe insomnia symptoms	20 (41.7)
Chronic daytime sleepiness/fatigue <sup>a</sup>	8 (16.7)
Comorbid sleep-related breathing disorder	11 (22.9)
Conclusions of HPSG	Number of patients (%)
No pathological findings	23 (47.8)
Extended total sleep time (> 10 hours)	2 (4.2)
Periodic limb movements	1 (2.1)
Delayed sleep-phase disorder	3 (6.3)
Global sleep insufficiency	3 (6.3)
REM phase insufficiency	3 (6.3)
N3 phase insufficiency	1 (2.1)
Obstructive sleep apnea	10 (20.7)
Non-interpretable polysomnography	2 (4.2)

<sup>a</sup> Referring to patients with neurological disease (Parkinson disease, multiple sclerosis...) exhibiting awakening and/or sleep disturbance; HPSG: home polysomnography; REM: rapid-eye-movement.

sleep-related neurological disorders for 13 patients (27.1%); 10 patients (20.1%) fulfilled the criteria of OSA and 23 HPSG (47.9%) revealed no pathological findings.

## Discussion

With a rate of 72.9% of satisfactory recordings, this observational pilot study was within the range of previous studies [12,14] and confirmed the feasibility of performing PSG at home. Our results showed that the main cause of unsatisfactory HPSG was due to EEG data loss (27.1% of tracings), being more prevalent than respiratory data loss (14.6% of tracings). Signal failure tended to preferentially affect respiratory sensors [3,4]. However, depending on the sensor type (oximetry, EEG leads or body bands), the duration of signal failure might show substantial inter-patient variability [3], which could counterbalance this trend in another population. Moreover, the population screened for sleep-related breathing disorders is different from that screened for sleep-related neurological disorders. The latter may exhibit different phenotypes such as lower body mass index and/or variant nocturnal behaviors leading to the loss of other sensors. In everyday practice, sleep technicians should take particular care in setting up secure EEG sensors in such a population.

HPSG has been extensively used for studying the relationships between sleep-related breathing disorders and

cardiovascular morbidity (SHHS cohort). With this aim, the required quality of recordings ranged from grade "good" to "fair" or "sufficient", which lowers from 5 hours (i.e. 50% of sleep time) to 4 hours (i.e. 40% of sleep time), the time of continuous recording needed [11,13]. In sleep-related breathing disorders, the rate of acceptable recordings with a grade varying from "good" to "fair", ranged from 75% to 94.7% [12,14]. Unlike most of these studies, we used stricter criteria and included only HPSG recordings of higher quality (66% of sleep time required), in order to allow study of sleep architecture over the longest duration possible, necessary in the context of investigating sleep-related neurological disorders. However, this cut-off may be still insufficient in some sleep-related neurological disorders. For example, the diagnosis of idiopathic hypersomnia requires extended recording time to measure the total amount of sleep per day [1]. In this context, for a 24-hour period recording, the sleep technician would have to disconnect the material the following evening rather than the following morning, after completing overnight recording. In such a case, the standard attended in-laboratory PSG remains a better choice.

The main drawback of this study was the lack of video recording due to confidentiality issues. We had to focus only on periodic limb movement disorders and could not include patients suspected of REM sleep behavior disorder. Extended studies with video monitoring would enable fuller investigation of sleep-related movement disorders, as well as parasomnias, which have to be clinically described. Lastly, the diagnosis of narcolepsy with or without cataplexy requires a MSLT to estimate objective sleepiness [1]. In our study, patients suspected for narcolepsy were systematically referred to the sleep laboratory to perform the MSLT the day following the recorded night. Because of the lack of data about home MSLT, a full out-of-laboratory exploration combining PSG and MSLT for patients suspected of narcolepsy remains challenging.

In a recent study, costs have shown to be lower with HPSG compared to sleep-laboratory PSG in suspected OSA [5]. In our work focusing on suspected sleep-related neurological disorders, the cost of HPSG was 350€ in agreement with the French RHA. However, for the purposes of this study, HPSG portable devices were rented at a cost of 140€ per patient and data were managed by a private society for 50€ per patient. This drastically increased the costs of carrying out HPSG. In everyday practice, we could expect relative lower costs closer to the threshold of the current level of reimbursement by the French health service of 181.53€ for this examination [7]. That said, the aim of this study was to assess feasibility of out-laboratory PSG compared to in-laboratory PSG. The cost of the latter is currently 514.03 euros [2]. While maintaining a high quality of recording, a one-night HPSG could save almost 164 euros, i.e. around one third of the current cost of in-laboratory PSG. Lower costs for substantial medical benefits could reduce global medical expenditures. Moreover, this could lead to higher reimbursement of HPSG by the French health service than of in-laboratory PSG. To carry out an accurate medico-economic assessment, further studies are needed and must also take into account the costs of additional in-laboratory PSG due to unsatisfactory HPSG recordings [4].



## Conclusions

Prescribed for suspected sleep-related neurological disorders and with allocated charges around one third lower compared to in-laboratory costs, HPSG is clearly feasible. Nevertheless, additional in-laboratory explorations and video monitoring are still required for the diagnosis of idiopathic hypersomnia, narcolepsy, and REM sleep behavior disorder, respectively. Beyond the feasibility of performing PSG at home, further studies are needed to measure the real medico-economic impact of promoting out-laboratory explorations for sleep-related neurological disorders.

## Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

## Acknowledgements

This work was supported by the French Regional Health Agency of Lorraine and by the federation of municipalities of Nancy grants.

**Funding:** In particular, the authors have no financial interests with Clinact® or HADAN® societies.

## References

- [1] American Academy of Sleep Medicine. The international classification of sleep disorders: diagnostic and coding manual. 2nd ed. Westchester, Ill: American Academy of Sleep Medicine; 2005 [297 p.].
- [2] La ministre des affaires sociales et de la santé, pour la ministre et par délégation: le directeur général de l'offre de soins, J. Debeaupuis. Le ministre de l'économie et des finances, pour le ministre et par délégation: Le directeur de la sécurité sociale, T. Fatome. Arrêté du 22 février 2013 fixant pour l'année 2013 les éléments tarifaires mentionnés aux I et IV de l'article L. 162-22-10 du code de la sécurité sociale et aux IV et V de l'article 33 modifié de la loi de financement de la sécurité sociale pour 2004 [Internet]. Paris: Direction de l'information légale et administrative. JORF; 2013. Available from: [http://www.legifrance.gouv.fr/affichTexte.do;jsessionid=5D2FD3D25EF861792104DD0D542D809C.tpdjo09v\\_3?cidTexte=JORFTEXT000027115074&categorieLien=id](http://www.legifrance.gouv.fr/affichTexte.do;jsessionid=5D2FD3D25EF861792104DD0D542D809C.tpdjo09v_3?cidTexte=JORFTEXT000027115074&categorieLien=id)
- [3] BaHammam AS. Signal failure of type 2 comprehensive unattended sleep studies in patients with suspected respiratory sleep disordered breathing. *Sleep Breath* 2005;9(1): 7–11.
- [4] Bruyneel M, Ninane V. Unattended home-based polysomnography for sleep disordered breathing: current concepts and perspectives. *Sleep Med Rev* 2014;18(4):341–7, <http://dx.doi.org/10.1016/j.smrv.2013.12.002> [Epub 2013 Dec].
- [5] Bruyneel M, Sanida C, Art G, Libert W, Cuvelier L, Paesmans M, et al. Sleep efficiency during sleep studies: results of a prospective study comparing home-based and in-hospital polysomnography. *J Sleep Res* 2011;20(1 Pt 2):201–6.
- [6] Campbell AJ, Neill AM. Home set-up polysomnography in the assessment of suspected obstructive sleep apnea. *J Sleep Res* 2011;20(1 Pt 2):207–13.
- [7] Study group of Cnamts. Code AMQP012 [Internet]. Paris: Cnamts. Direction de la communication. CCAM; 2013. Available from: <http://www.ameli.fr/accueil-de-la-ccam/trouver-un-acte/fiche-abregee.php?code=AMQP012>
- [8] Ferber R, Millman R, Coppola M, Fleetham J, Murray CF, Iber C, et al. Portable recording in the assessment of obstructive sleep apnea. *ASDA standards of practice. Sleep* 1994;17(4): 378–92.
- [9] Gruber R, Xi T, Frenette S, Robert M, Vannasinh P, Carrier J. Sleep disturbances in prepubertal children with attention deficit hyperactivity disorder: a home polysomnography study. *Sleep* 2009;32(3):343–50.
- [10] Iber C. The AASM manual for the scoring of sleep and associated events - Rules, terminology and technical specifications. Westchester, IL: American Academy of Sleep Medicine; 2007.
- [11] Iber C, Redline S, Kaplan Gilpin AM, Quan SF, Zhang L, Gottlieb DJ, et al. Polysomnography performed in the unattended home versus the attended laboratory setting-Sleep Heart Health Study methodology. *Sleep* 2004;27(3):536–40.
- [12] Kapur VK, Rapoport DM, Sanders MH, Enright P, Hill J, Iber C, et al. Rates of sensor loss in unattended home polysomnography: the influence of age, gender, obesity, and sleep-disordered breathing. *Sleep* 2000;23(5):682–8.
- [13] Quan SF, Griswold ME, Iber C, Nieto FJ, Rapoport DM, Redline S, et al. Short-term variability of respiration and sleep during unattended nonlaboratory polysomnography-the Sleep Heart Health Study. [corrected]. *Sleep* 2002;25(8): 843–9.
- [14] Redline S, Sanders MH, Lind BK, Quan SF, Iber C, Gottlieb DJ, et al. Methods for obtaining and analyzing unattended polysomnography data for a multicenter study. *Sleep* 1998;21(7):759–67.